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LASER WELDING OF QUARTZ LIGHT GUIDES

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A laser welder and a technology for welding quartz light guides are described. Results of testing mechanical properties of welded light-guide bundles are given.

Permanent joints of light guides are required in fiber-optics information transfer systems [1 – 6]. This is primarily needed for the development of extended communication lines consisting of light guides of limited length, for connecting various electro-optical devices to a fiber-optic line, and for making light-guide splitters.

The most common method for obtaining a nondetacheable joint is welding light guides, which makes it possible to produce a permanent joint with low optical losses, high strength, and high communication stability.

The heating sources in available welders include arc discharge, gas burner flame, and radiation of CO_2 laser [2 – 6]. The most common is arc welding. Welders with a laser heating source are used only in laboratories. The advantages of a laser heating source consist in localized heating of a light guide and its absolute sterility [2 – 3] and are little studied.

A special set has been designed for welding light guides using laser radiation [2], whose diagram is shown in Fig. 1. Its main components are as follows: CO and CO_2 lasers *1* and *2* (6 and 30 W, wavelength 5 – 6 and 10.6 μm), an optical divider *3*, a power meter of IMO-2N type *4*, and an adjustable attenuator *5* (since the lasers used have plane-polarized radiation, the attenuator has a rotary vane made of gallium arsenide installed at the Brewster angle); the beam is interrupted with an interrupter based on an electromagnetic relay *6*.

The optical train *7* focuses radiation toward the stage zone, in which the light guides *9* are fixed in *V*-shaped holders *8* using magnetic clamps. A MBS-9 microscope *10* is installed in the zone of laser beam constriction and used to adjust the light guides.

Since the main purpose of our study is welding a bundle of light guides for compound cables and splitters, the sets use cylindrical optics (Fig. 2) consisting of a ZnSe lens and a reflecting metallic mirror, making it possible to create a caustic, i.e., a cylinder-shaped heated zone 2 – 4 mm in diameter and over 10 mm long. This shape of the focusing zone allows for welding splitters and compound flat cables.

Light guides prepared for welding were fixed on micrometric stages with magnetic clamps and aligned with respect to each other (Fig. 1). Next, the light guides at distances of about 10 μm were fused for 0.5 – 1 sec with laser radiation to get slight but visible fusion. After that, the light guides were placed together and the power of the laser radiation was increased using the attenuator to a degree required for softening quartz glass (1800 – 2000°C). During welding (0.5 – 5 sec) the light guides were first brought together, upon which the light guide diameter became slightly thicker, and then stretched to produce a uniform diameter along the entire length. After that, radiation was switched off.

The optimum radiating power of CO and CO_2 lasers for obtaining weld joints was 1.0 – 1.3 W.

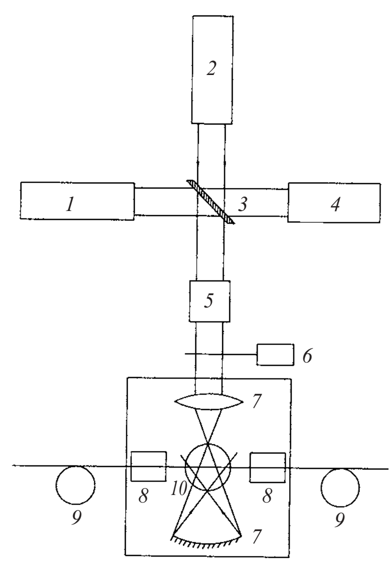

Fig. 1. Scheme of a set for welding quartz light guides based on CO and CO_2 lasers.

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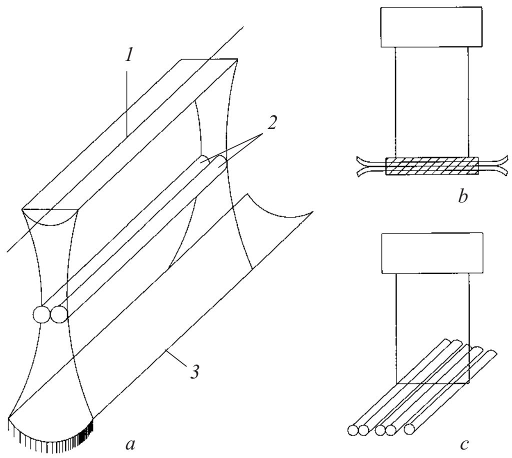

Fig. 2. Optical train for welding light guides: *a*) focusing zone; *b* and *c*) welding of splitters and flat cables, respectively; *1*) cylindrical ZnSe lens; *2*) light guides; *3*) cylindrical mirror.

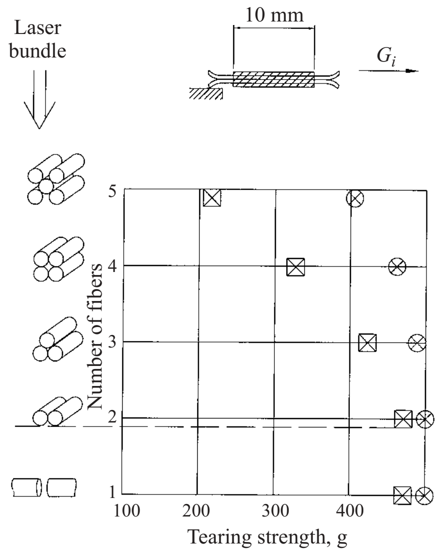

Fig. 3. Mechanical strength of joints of quartz light guides: ⊠) CO_2 laser (10.6 μm); ⊗) CO laser (5 – 6 μm).

Welding light guides by laser radiation consumes about 0.5 J, whereas arc welding consumers up to 90 J. The upgraded air-cooled lasers have significantly smaller sizes (up to 0.2 × 0.2 × 0.3 m) and weigh up to 5 kg, which allows their application in contemporary communication technologies.

In addition to optical losses, the mechanical strength of welded joints was measured as well. The measurements were performed on a set identical to the one described in [4].

A specific feature of the experimental welder is using a CO laser as a heating source (5 – 6 μm), whose radiation penetrates into quartz glass to a depth about 200 μm, i.e., deeper by an order of magnitude than radiation of a CO_2 laser. Consequently, it was to be expected that a uniform release of energy by the CO laser within a short time period in the light guide volume would make it possible to localize the melting zone. This is especially important in welding single-mode light guides, where distortions of the shape of core are especially undesirable. This can be implemented only in the case of deep penetration of laser radiation into the material and high radiation density.

More than 200 samples were obtained to compare parameters of welded lightguide joints using CO and CO_2 lasers.

With respect to optical losses, especially in welding single-mode light guides, CO laser is more promising, subject to using high-precision adjusting devices (for instance, piezoadjusters with an accuracy of 0.01 μm). In welding multi-mode lasers there is no significant difference in the type of laser used.

We investigated the possibility of creating complex profiles in heating zones for laser welding of several light guides (for instance, welding flat fiber-optic cables and splitters [5]).

The simplest method for welding several light guides or splitters is using a spherical lens focusing laser radiation on the light guides in welding. However, high radiation power is needed to ensure sufficient power density for welding. Another welding method is using focused laser radiation that is scanned with various devices from one light guide to another. This method is better than the first one; however, it requires a complex scanning system and welding of splitters becomes more complicated.

The simplest method for solving this problem is to use cylindrical optics. A radiation spot focused by such a lens is a band with a side ratio of 10 : 1 (Fig. 2). Lenses made of clarified zinc selenide used in the particular lasers in the set described above allowed for welding five light guides. Using such lenses to weld a pair of light guides lowers the requirement imposed on alignment of one coordinate, which is clearly seen in Fig. 2*a*.

It is known [5] that X- and Y-shaped splitters are the most common ones in communication systems. To ensure the welding process, especially in X-shaped splitters, it is necessary to heat and soften a pair of light guides along a rather substantial length: 1 – 10 mm. Accordingly, the use of cylindrical lenses in laser welding of such splitters is optimal.

We tested welding of several light guides to a length of 1 – 10 mm using radiation of CO and CO_2 lasers. Multimode light guides 125 μm in diameter were welded in these tests. The light guides were coated by a protective polymer coating. The number of light guides welded was 2, 3, 4, and 5 (Fig. 3). The mechanical strength of the joints obtained was satisfactory. Mechanical testing of the light guide bundles was performed by measuring the force of tearing a single light beam from the bundle. Depending on the number of light guides in the bundle, the average strength of the joint was calculated as the mean value:

$$\sigma_{av} = \frac{1}{N} \sum_{i}^{N} \sigma_i .$$

The results of these experiments showed that the CO laser has a significant advantage in welding a bundle of light

guides. First, the strength of a bundle of light guides is higher than welded with a CO_2 laser (the probability of a single light guide being torn from the bundle is lower), second, the geometric characteristics of the light guide bundle are better.

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